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## Profile

# Filtration Fundamentals: Is Knowledge Of Filter Technology Something You Let Fall Through The Cracks?

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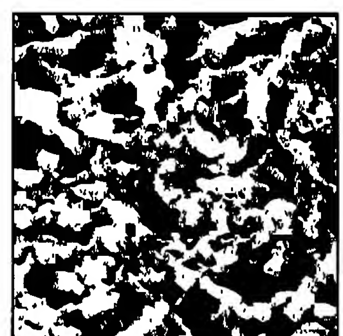
Filtration Table

An article on filters? Nah, filters are too simple. You put a small paper cone in the filter holder, add coffee, and pour on hot water. Drip, drip, drip, and the coffee's ready. That's all there is to it. But hold on a minute. There are thirty grades of Whatman standard filter paper alone, and even if we restrict ourselves to a biological laboratory, we have depth filters and screen filters; filters with different pore sizes that are tightly or loosely dispersed; packaging that employs prefilters, sheets, bags, tubes, or hollow fibers; filtration systems that use gravity, centrifugal force, vacuum, or pressure pumps; and systems that use a variety of different flow geometries (not even considering the closely related technology of binding assay membranes). Yet most people who simply use filtration as a "routine technique" in the laboratory give about as little thought to the process as they do to the decision to buy generic or brand-name coffee filters.

Instead of looking at specific applications or examining the different syringe, bottle-top, centrifuge, capsule, cartridge, and myriad other filter holders, this article will outline some filtration basics and will focus on manufacturing and materials rather than applications and specialized holders, paying exclusive attention to the role of filters.



Cross section of nitrocelluose membrane. Electron micrograph courtesy of Schleicher and Schuell

Filtration can be loosely classified by the size or nature of the particles being removed from the liquid or gas being purified. Many companies break this spectrum down into five broad classes: macrofiltration, microfiltration, ultrafiltration, nanofiltration, and reverse osmosis.

Macrofiltration is the coarsest category. Similar to every laboratory's core activity of removing coffee grounds from a flavored caffeine solution, macrofiltration generally involves removing particles larger than 1/20 millimeter. Sorting big rocks from small rocks at the local quarry would fall into the macrofiltration class, but for practical laboratory purposes we can accept an upper size range of a millimeter or so. For example, Whatman-type paper filter discs, as well as many different styles of glass, ceramic, and polymer prefilters, fall into this category.

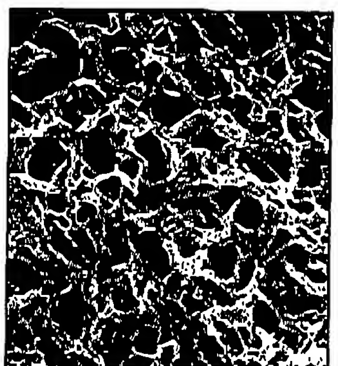
Microfiltration is at the smaller end of the particulate filtration spectrum. Microfiltration generally doesn't cover dissolved materials but will remove particulates between 0.2 µm and 10 µm. Most microfiltration filters are manufactured from polymeric materials, although some glass, ceramic, and even metal filters are available. Most filters fall into the microfiltration and ultrafiltration range, although a similar technology is used to produce filters for nanofiltration and reverse osmosis. Microrganisms are removed for fluid sterilization by this class of filters. Analytical test procedures are numerous using these filters.

Ultrafiltration uses membranes to separate different organic macromolecules. An ultrafiltration membrane is

generally semipermeable and requires considerable energy or force to effect the separation. Capable of concentrating bacteria, virus particles, and proteins, ultrafiltration is appropriate for molecules with molecular weights ranging from 1,000 to 1,000,000 Daltons. (Microfiltration, because it deals primarily with solids, is usually described in terms of particle size; ultrafiltration, because it can additionally be used to separate dissolved material, is generally described in terms of molecular weight.)

Nanofiltration also uses membranes to separate different fluids or ions. The pores in a nanofiltration membrane are much smaller than those in an ultrafiltration membrane, so the energy required to drive the system is much greater. However, a nanofiltration process will eliminate most particles with molecular weights over 1,000 Daltons. In some ways, nanofiltration can be thought of as a process that lies somewhere between ultrafiltration (where the size and shape of a particle is responsible for its rejection by the filter) and the fifth broad category, reverse osmosis (where it is the charge on the particle that leads to separation at the ion level).

Reverse osmosis effects the most difficult separations, employing a semipermeable membrane with the smallest pores and consuming the greatest amount of energy. Reverse osmosis will eliminate particles close to 100 Daltons. This means that the membrane will reject bacteria, viruses, most proteins, and many other small particles. However, the power of reverse osmosis comes from the fact that charge plays a far greater role in the separation than do size and shape, so much smaller particles are rejected by the charged membrane. Dissolved particles, if charged, will also be rejected by the membrane, even when the physical size of the dissolved material is considerably smaller than the pores. Because many common water contaminants carry a charge, such as salt, reverse osmosis is commonly used in water purification systems or desalination.



PVDF membrane. Electron micrograph courtesy of Millipore

The simplest membrane is the depth filter. Before looking at some of the materials used to manufacture filters, we should briefly examine the basic types of membranes. The paper funnel used to filter coffee is a form of depth filter; a depth filter can be thought of as a sheet or plug of material composed of randomly arrayed fibers or particles. The size of the particles or fibers, the density at which they are packed, and the means by which they are held together will influence the spaces between them. These spaces form a convoluted path that will allow passage of a gas or liquid as well as particles up to nominal defined size and shape. Depth filters are manufactured using three different approaches.

For (often) crude applications, depth filters are manufactured by packing the filter material in a controlled fashion and bonding the particles/fibers appropriately. Perhaps the easiest to understand is the sintered glass filters that are commonly built into some kinds of glassware. Glass fibers or pellets are packed into a mold and subjected to heat and pressure. As the glass softens, it deforms and sticks together to create a "frit" of defined shape and thickness. The tortuous paths through the frit are controlled by the initial size of the particles and the amount of heat and pressure applied. This approach is taken for many glass and metal filters (when performed using metals, the product is usually referred to as molecularly bonded rather than sintered), but it is less commonly used with polymers. Silver metal membranes may be used directly for scanning electron microcopy (SAM) applications. They are also widely used for x-ray diffraction applications.

Polymeric membrane filters are most commonly manufactured polymer filters or mats with a bonding material. The majority of membranes sold for microfiltration and ultrafiltration are manufactured using a controlled solvent evaporation process. Polymer is dissolved into an appropriate solvent. In a continuous process, a thin layer (often less than 0.2 mm) of the polymer solution is spread onto a moving belt and the solvent allowed to evaporate in a precisely controlled manner. As the solvent evaporates, channels and cavities form in the material, surrounded by blobs, fibers, and microscopic sheets of polymer. Surprisingly, this highly random process can result in membranes with absolute pore-size ratings. The majority of materials (including PVC, PTFE, nylon, and PES) used in polymeric filters are formed using this process.

Because of limitations imposed by the properties of the material used, some polymeric filters are manufactured by the controlled stretching of a sheet of material. As the sheet is stretched, a combination of stretching and tearing leads to the creation of tortuous paths through the material. PTFE and polypropylene filters are manufactured using this process.

More control is achieved by making precisely defined holes in an otherwise unbroken sheet of polymer, resulting in a membrane or screen filter. Such filters are manufactured using a process that gives control over the final product. A sheet of material is cast in an appropriate thickness. It is then passed over a